A Note on the Energy Structure Theory and Development for 2D Viscoelasticity

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ABSRACT--- ***The basis of the Energy Structure Theory can be introduced in references [1-5] presented in 2020. Energy Structure Theory explains some new thermo-physical concepts including energy space, energy structure equation, dependent and independent energy components, irreversibility components, irreversibility structure, etc. Since this theory is presented considering the first and second laws of thermodynamics as well as energy components of the system as the basis of the energy structure equation, this theory can be expanded for a variety of the scientific applications. For example, in this note, we will try to introduce some of these scientific applications in general physics and engineering analysis. Also, using relevant concepts, 2D viscoelasticity problems will be studied. Also, the viscoelasticity and kinematic energy will be calculated for 2D viscoelasticity problems. Energy structure theory let us to study physical processes from the perspective of the componential energy exchange as well as independent and dependent energy component concept introduced by this theory.***

Keywords--- Energy Structure Theory; Energy components; Energy structure equation; Energy conservation principle; Irreversibility structure; Statistical physics; Viscoelasticity

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1. INTRODUCTION

From the perspective of the physical science, principles of conservation examine the quantitative concepts in physical processes. For example, energy conservation, linear and angular momentum conservation, mass conservation, etc., which can be applied to physical phenomena, and every physical process must be performed in such a way that these principles are satisfied. Among the physical laws, the only physical law that considers the concept of direction of processes is the second law of thermodynamics [6]. Carnot could be known as the founder of this law, because he introduced reversible processes in him paper before the first law was introduced [7].

Irreversibility is one of the most important concept in physics introduced by the second law of thermodynamics. When a physical process is performed, the instantaneous reversal of the motion of every moving particle causes the system to move backward, each particle along its old path at the same speed as before when in the same position. From the perspective of the physical dynamics of the particles(or sub-structures), this simple and perfect reversibility fails, on account of forces depending on the friction of solids; imperfect fluidity of fluids; imperfect elasticity of solids; inequalities of temperature, and consequent conduction of heat produced by stresses in solids and fluids; imperfect magnetic retentiveness; residual electric polarization of dielectrics; generation of heat by electric currents induced by motion; diffusion of fluids, solution of solids in fluids and other chemical changes and absorption of radiant heat and light. Also to investigate the energy dissipation in physical processes, the dynamics of the particles (or sub-structures) can be studied [8-12].

The first law of thermodynamics explains the conservation of energy, while the second law explains the physical direction of feasible processes. Carnot introduces the irreversible processes and using them, extracts upper work bound in a thermodynamic cycle [3]. Also, Shahsavari extracts a lower work bound for a thermodynamic cycle by the combination of the first and second law of thermodynamics directly [3]. Inspired by these facts, Energy Structure Theory presents an energy structure equation [1].

Energy structure equation has a quasi-statistical base and is presented based on the activated energy components [1,2]. This theory explains some new concepts as independent and dependent energy components. In fact, using the concepts introduced by Energy Structure Theory, a variety of physical and engineering problems can be studied [1,2,4,5].

In this note, at first, an introduction to the energy structure equation as well as energy structure theory basis is presented. Also, some of the potential scientific applications of this theory, relevant to the general physics and engineering applications, are introduced. And also, these potentially applications are studied using energy structure theory approach.

2. ENERGY STRUCTURE EQUATION

Equation (1) presents the energy structure equation can be used for studying physical processes [1]:

$$U_T = (u_1 + u_2 + \cdots + u_m) + [g_1 + \cdots + g_k] + [h_1 + \cdots + h_n] + U_{T_0} \quad (1)$$

Where:

$$g_j = g_j(u_1, u_2, \dots, u_m) \quad (2)$$

$$h_p = h_p(\dot{u}_1, \dots, \dot{u}_m) \quad (3)$$

That u_i is energy component is activated in the performed process. Also g_j and h_p are activated dependent components. The term U_{T_0} is part of the energy that does not change in the performed process.

Equation (1) is written based on the activated energy components and has a quasi-statistical base [4]. This equation is in the same line as the second law of thermodynamics [1,13].

Using studying energy structure equation in different paths, the performed process and relevant quantities can be investigated.

3. SOME OF THE POTENTIAL SCIENTIFIC APPLICATIONS

In this part, due to the basis of the energy structure theory, some of the potential applications for this theory will be introduced.

3.1. Statistical physics

Equation (1) has the same base as statistical physics concepts. In fact, an energy structure equation will be formed for a particular physical process. For each considered process, depend on the condition of the energy applying, some of the energy components will be activated. Some of the activated components will be activated as dependent components and the remaining will be independent.

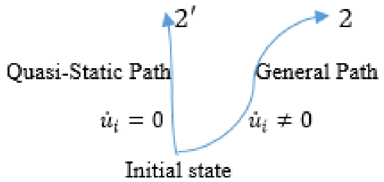

Figure 1. Scheme of the statistically base of the energy structure equation

As some equal energy is applied to the system in different paths, Equation (4) can be rewritten based on the energy structure equation of the system:

$$\left(1 + \sum_{j=1}^{k}\left(\frac{\partial g_j}{\partial u_i}\right)\right)(\delta u_i - \delta u'_i) = -\left(\sum_{p=1}^{n}\left(\frac{\partial h_p}{\partial \dot{u}_i}\right)\right)\delta \dot{u}_i \quad (4)$$

Equation (4) can relate different paths to each other and must be established for all energy components u_i. When the condition of energy applying changes, this equation, also must be governed on the new process. Therefore, equation (4) has the same base as the statistical physics concept [4]. Also, equation (4) is in the same line as the different approach of the second law of thermodynamics [14-16].

3.2. Engineering: 2D viscoelasticity

In this part, the energy structure equation for 2D viscoelasticity is extracted. The energy structure equation is extracted for 1D viscoelasticity in reference [5]. The variation of viscoelasticity energy can be rewritten as follows:

$$\delta U_{VE} = \alpha \delta U_T + \beta \delta \dot{U}_T \tag{5}$$

And also:

$$\delta U_{VE_s} = \alpha_s \delta U_T \tag{6}$$

$$\delta U_{VE_d} = \alpha_d \delta U_T + \beta \delta \dot{U}_T \tag{7}$$

And the variation of the kinetic energy in a process can be written as follows:

$$\delta U_K = (1-\alpha)\delta U_T - \beta \delta \dot{U}_T \tag{8}$$

Equation (8) takes the kinetic energy of the body in the function of the amount and rate of applied energy to the body as well as coefficients α and β.

The first example: Two-axis loading

Figure 2 shows a viscoelasticity element under two-dimensional uniform stress:

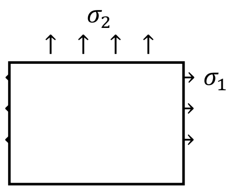

Figure 2. Viscoelasticity element under two-dimensional uniform stress

In this problem, Poisson's ratio will be effective in viscoelasticity energy. Therefore the suitable g_j functions must be used. By using of the results of the first example as well as linear elasticity, the bellow equation can state the structure of viscoelasticity energy:

$$U_{VE} = u_{e1} + u_{e2} + k\sqrt{u_{e1}u_{e2}} + c_{e1}\dot{u}_{e1} + c_{e2}\dot{u}_{e2} + c \tag{9}$$

That u_{e1} and u_{e2} are the independent components as elastically energies that are activated in loading is shown in figure 2. And also, $g_i = k\sqrt{u_{e1}u_{e2}}$, $h_{e1} = c_{e1}\dot{u}_{e1}$ and $h_{e2} = c_{e2}\dot{u}_{e2}$ are dependent components. In the case of $u_{e2} = 0$, equation (9) will be equivalent to a 1D viscoelasticity element.

Also the coefficients α and β:

$$\alpha = \alpha_{e1}\left(1 + \frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right) + \alpha_{e2}\left(1 + \frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right) + c_{e1}\dot{\alpha}_{e1} + c_{e2}\dot{\alpha}_{e2} \tag{10}$$

$$\beta = c_{e1}\alpha_{e1} + c_{e2}\alpha_{e2} \tag{11}$$

Therefore:

$$\delta U_{VE} = [\alpha_{e1}\left(1 + \frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right) + \alpha_{e2}\left(1 + \frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right) + c_{e1}\dot{\alpha}_{e1} + c_{e2}\dot{\alpha}_{e2}]\delta U_T + (c_{e1}\alpha_{e1} + c_{e2}\alpha_{e2})\delta \dot{U}_T$$

,(12)

$$\delta U_K = [1-(\alpha_{e1}\left(1+\frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right)+\alpha_{e2}\left(1+\frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right)+c_{e1}\dot{\alpha}_{e1}+c_{e2}\dot{\alpha}_{e2})]\delta U_T-(c_{e1}\alpha_{e1}+c_{e2}\alpha_{e2})\delta\dot{U}_T$$
(13)

Equations (12) and (13) give the viscoelastic and kinetic energy of the system. And also:

$$\delta U_{VE_s} = [\alpha_{e1}\left(1+\frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right)+\alpha_{e2}\left(1+\frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right)]\delta U_T \quad (14)$$

$$\delta U_{VE_d} = [c_{e1}\dot{\alpha}_{e1}+c_{e2}\dot{\alpha}_{e2}]\delta U_T+[c_{e1}\alpha_{e1}+c_{e2}\alpha_{e2}]\delta\dot{U}_T \quad (15)$$

The effects of Poisson's ratio are considered in relevant constant coefficients.

The second example: Plane stress

A viscoelasticity element under plane stress is shown in figure 3:

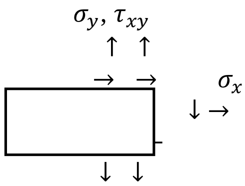

Figure 3. Viscoelasticity element under plane stress

The bellow equation can be used for viscoelasticity energies:

$$U_{VE} = u_{e1}+u_{e2}+u_{e3}+k\sqrt{u_{e1}u_{e2}}+c_{e1}\dot{u}_{e1}+c_{e2}\dot{u}_{e2}+c_{e3}\dot{u}_{e3}+c \quad (16)$$

The component u_{e3} is used for considering the effects of shear stress, and also $h_{e3}=c_{e3}\dot{u}_{e3}$ is a dependent component because of this energy component.

The coefficients α and β:

$$\alpha = \alpha_{e1}\left(1+\frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right)+\alpha_{e2}\left(1+\frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right)+\alpha_{e3}+c_{e1}\dot{\alpha}_{e1}+c_{e2}\dot{\alpha}_{e2}+c_{e3}\dot{\alpha}_{e3} \quad (17)$$

$$\beta = c_{e1}\alpha_{e1}+c_{e2}\alpha_{e2}+c_{e3}\alpha_{e3} \quad (18)$$

And also:

$$\delta U_{VE} = [\alpha_{e1}\left(1+\frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right)+\alpha_{e2}\left(1+\frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right)+\alpha_{e3}+c_{e1}\dot{\alpha}_{e1}+c_{e2}\dot{\alpha}_{e2}+c_{e3}\dot{\alpha}_{e3}]\delta U_T+(c_{e1}\alpha_{e1}+c_{e2}\alpha_{e2}+c_{e3}\alpha_{e3})\delta\dot{U}_T \quad (19)$$

$$\delta U_K = [1-(\alpha_{e1}\left(1+\frac{k}{2}\sqrt{\frac{u_{e2}}{u_{e1}}}\right)+\alpha_{e2}\left(1+\frac{k}{2}\sqrt{\frac{u_{e1}}{u_{e2}}}\right)+\alpha_{e3}+c_{e1}\dot{\alpha}_{e1}+c_{e2}\dot{\alpha}_{e2}+c_{e3}\dot{\alpha}_{e3})]\delta U_T-(c_{e1}\alpha_{e1}+c_{e2}\alpha_{e2}+c_{e3}\alpha_{e3})\delta\dot{U}_T \quad (20)$$

Equations (19) and (20) give the viscoelastic and kinetic components energy of the body shown in figure 3.

4. CONCLUSIONS

Energy structure theory introduces some new concepts including energy space, energy structure equation, dependent and independent energy components, irreversibility components, irreversibility structure, etc. This theory uses these concepts to extract a general view of the physical processes. In the energy structure theory, energy components are used as the basis for extracting relevant equations.

Due to the fact that energy structure theory applies the effects of the second law of thermodynamics on the energy conservation principle, directly using a quasi-statistical approach, this theory will have a variety of scientific applications. In fact, this theory presents the energy structure equation inspired by the first and second laws of thermodynamics. Also, the energy structure equation has the same base as the different formulations of the second law of thermodynamics.

By studying the energy structure equation in different conditions of energy applying to the system, equation (4) will be extracted as the fundamental equation between different paths. This equation has the same base as the statistical physics concepts.

As an applied engineering example, the energy structure equation was used to studying 2D viscoelasticity. The relevant equations were extracted, and also viscoelasticity and kinematic energy are calculated. Writing equations in the energy space of the system makes it possible that the energy paths of the system will be detected, and this can be very important in viscoelasticity.

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